METHOD AND APPARATUS FOR THE ELECTRIC MEASUREMENT OF PHYSICAL VALUES, FOR EXAMPLE, MEASUREMENT OF MECHANICAL STRESSES

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16. Abstract

Resistance and reactance measuring devises are described with application to the following: thermometer, bolometer, force transducer, moisture, magnetic field frequency, light intensity, stress. Several measuring bridges are presented, which incorporate compensating, amplifying and conditioning circuits. Applications include stress measurements in propellors of flying aircraft from ground stations. Stress shock pulses can be measured with the devices as well as high frequency stress pulses.

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METHOD AND APPARATUS FOR THE ELECTRIC MEASUREMENT OF PHYSICAL VALUES, FOR EXAMPLE, MEASUREMENT OF MECHANICAL STRESSES

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This invention concerns the electric measurement of physical values with the aid of transmission instruments, which indicate a change in an electric value resulting from a change in the physical value being measured. Such instruments may be of complex design, for example like a capacitance microphone or a gramophone cartridge; however, they may also be simple, for example like a resistance-measuring device for measuring mechanical stress, a resistance thermometer, a bolometer, or instruments for force measurement. In the description that follows, we shall call all such instruments measuring instruments for the sake of simplicity. Such instruments may be designed to measure mechanical stress in a test specimen, temperature, moisture, light intensity, frequency of a magnetic field, or other physical values. /1*

* Translator's Note: Numbers in margin indicate pagination of original foreign text.

It is customary to connect a measuring instrument for mechanical stress to a branch of a Wheatstone bridge and to supply the bridge with d.c. or a.c. current; in such cases the voltage is measured at the ends of the galvanometer diagonals and the ratio between the input and output /2 voltages is regarded as a measure of the change that took place in the mechanical stress on the test specimen or part. In such an instrument — especially in cases where the circuit is supplied with direct current — the major characteristic for the evaluation of the system depends on the sensitivity of the readout instrument in the galvanometer diagonal. It is difficult — especially in the case of circuits containing an amplifier — to maintain the input voltage at a constant reference level. This difficulty is partly alleviated by feeding the system with alternating current; however, in this case the bridge must be brought to an equilibrium both with respect to effective resistance and blind resistance, and additional difficulties are created by the fact that there may be scatter capacitances and upper harmonic vibrations in the circuit.

It was found that these difficulties may be significantly reduced or entirely eliminated by the use of electric input pulses with a bridge having a suitable amplifier and readout instrument in the galvanometer diagonal. If the system is operated in this manner, the bridge is easier to bring into equilibrium than in the case where excitation is accomplished with constant voltage and frequency. If direct current pulses are used at the input, the sign of the output voltage is indicated directly, and this is particularly advantageous in measurements using a single measuring instrument. In addition, operation with pulses simplifies simultaneous measurements at various locations as a result of the possibility of indicating the test values on a cathode-ray tube. In such cases the bridge may be supplied with high-frequency current pulses instead of direct-current pulses. In either type of excitation, a symmetric transformer arrangement in the circuit may be used instead of the bridge circuit.

One aim of this invention is to create an improved method and an apparatus for the electric measurement of mechanical stress in a test specimen or part, or for the measurement of another physical value by using conventional transmission devices in values of electric impedance. One of the particular features — although not the sole particular feature — of the invention covering the method and apparatus is the ability to carry out simultaneous measurement of physical effects at a number of locations, for example to determine mechanical stress at various areas of a test specimen or part or at different test specimens or parts, without the need for making the responding or indicating devices unduly complicated, or having to use several of them.

According to the invention, electric vibrations having a predetermined relation to a given physical value are generated in such a manner that a measuring instrument is fed with a series of pulses of electric energy having a relatively high repetition frequency, so that as a result, the measuring instrument is exposed to the appropriate effect so as to obtain a set of pulses that change with corresponding changes in the physical value concerned, and that, finally, the instrument indicates or measures the characteristic concerned.

The characteristic selected for measurement will depend on the design of the instrument; generally, however, it will be a pulse characteristic indicating its magnitude. Other characteristics such as amplitude or phase may also be selected, however.

Changes in the characteristic of the pulse are preferably indicated optically; a cathode-ray tube is suitable for this purpose.

A number of measuring instruments is fitted in various locations and each instrument is fed sequentially with pulses. This is the preferred arrangement. These pulses, which are changed by changes in the measuring instrument circuit, may be fed simultaneously to the same instrument, such as a single cathode-ray tube.

The pulses fed to a measuring instrument may be generated either by amplitude-modulation of a direct current or the amplitude-modulation of an alternating current; modulation may be 100%. Optionally, pulses may also be obtained by consecutive frequency-modulation of an alternating current in periods. If, in the latter case, several measuring instruments are used, each measuring instrument may be connected to the pulse source through a bandpass filter circuit that accommodates only a specific frequency range, and the alternating-current wave may, for example, be continuously frequency-modulated from an initial value to the final value, whereupon the modulation is rapidly reverted to the initial level.

In cases where the physical effect being measured occurs at a relatively inaccessible part, for example, in cases involving temperature or the mechanical stress of a moving part such as a propeller in a flying aircraft, the devices needed for carrying the altered pulses from the measuring instrument to the readout device may contain a cable or a radio transmitter and receiver, whereby the pulses to be measured are transmitted in the form of modulation of the carrier wave. Various measuring instruments may also be fed with pulses from a given source through a common cable connection, or each measuring instrument may be fed separately by means of capacitive or inductive coupling.

The invention also envisages a measuring instrument design in which the measuring instrument component is the terminal of a coaxial cable. In cases where the measuring instrument component is a resistor, the latter may consist of a conductive layer deposited on the elastic insulation substrate or mounted to it, with a conductive mantle surrounding the element. /3

Several embodiments of the invention shall now be described on the basis of the drawings; however, they are to be regarded as examples only.

Figure 1 is a schematic drawing of an embodiment containing several measuring instruments.

Figure 2 illustrates a typical image indicated on a cathode-ray tube when used as shown in Figure 1.

Figure 3 illustrates another form of the indicated image, in which the signal generated by each individual measuring element extends horizontally and vertically over the other signal.

Figure 4 is the circuit diagram of a simple measuring bridge, showing typical waveforms for the input and output pulses.

Figure 5 shows the components of part of the system defined by the pulse generator circuit illustrated in Figure 1.

Figure 6 illustrates an amplifier stage with a zero-point correction circuit connected to it; the purpose of the latter is to counteract the tendency of the zero point to shift in the a.c. amplifier illustrated in Figure 1. The tendency to shift results from its limited time constant.

Figure 7 is a diagram of a circuit used to control the zero-point shift and sensitivity of a measuring bridge.

Figure 8 is a circuit diagram of a measuring bridge for the measurement of frequencies.

Figure 9 is a block diagram of a system containing several measuring elements operated with high-frequency pulses.

Figures 10a and 10b illustrate alternating current waveforms as used in the system shown in Figure 9.

Figures 11 and 12 show embodiments of measuring element circuits in symmetric form, differing from the arrangement illustrated in Figure 2.

Figure 13 is a diagram of an arrangement for measuring stresses in an aircraft propeller blade in a flying aircraft.

Figures 14, 15, and 16 illustrate various designs of resistance measuring elements.

Wherever, in the description that follows, reference is made to resistance elements for measuring stresses in accordance with the terms of the invention, it should be realized that with any alterations, resistance or reactance measuring elements may also be used for measuring other physical values such as temperature, moisture, and the like, instead of measuring elements designed to measure mechanical stress.

The setup illustrated in Figure 1 consists of 10 similar measuring bridges 1, of which the outputs are connected in parallel and connected to an alternating-current amplifier circuit, while their input is fed by ten synchronized pulse generators 3. In a typical setup, the pulse-repetition frequency of each generator is 10 kHz per second, and the generators are connected in such a manner that they operate sequentially; an eleventh pulse generator is included in the circuit 3: it provides a gap period of the duration of a pulse during which a cathode-ray display device 4 may return to the time base. Owing to the fact that the amplifier 2 has a limited time constant and tends to exhibit a zero-point shift, the time interval in each period during the consecutive operations is also utilized to reset the amplifier output to zero in a manner to be described later.

The shape of each pulse is regulated by a shaping circuit 5, which in turn is controlled by a main oscillator 6, while an additional output of the shaping circuit 5 serves as a brightness control pulse for the cathode-ray tube 4. The temporal occurrence and the duration of the brightness control pulse may be adjusted so that the initial part of the output pulse which is perturbed by control reactances or effects on the circuit is left in the dark and the signal is brought to the desired degree of brightness only during the period of the wave height p (Figure 4). A third output of the shaping circuit maintains a step voltage generator 7 in synchronization; its output is fed either to the X electrodes of the cathode-ray tube 4 for generating a picture, of the kind illustrated in Figure 2, or the Y electrodes for generating a picture of the kind illustrated in Figure 3. A switch 8 is provided to permit selection to be made. If this switch is set to produce a picture of the kind illustrated in Figure 3, a sawtooth-shaped time base is fed from a sawtooth generator 10 to the X amplifier 9 of the X electrodes, while the step voltage is fed through the Y electrode amplifier 11 to the Y electrodes.

The picture of the kind illustrated in Figure 2 is such that each vertical signal 12 corresponds to the output of a measuring element in an appropriate bridge circuit 1, whereby the amplitude of each upper part 13 of a signal represents the magnitude of the change in the value of the physical property being measured, and the average height of the part 13 indicates the average value of the physical property above the common zero line. Thus, it is possible to measure easily the fluctuations of a physical property such as temperature or stress in various parts of a structure at the same time, and their relative magnitudes may be readily compared.

There may be cases where it is desirable to study in detail the fluctuations of the physical property represented by the various signals 13 in Figure 2 through their amplitudes. If, for example, the property being measured depends on the stress to which a vibrating part such as a propeller blade is subjected, the frequency of the time deflection voltage will be lower than the group-repetition frequency of the /4
pulses fed to the measuring elements 16, and synchronization with the vibration period in the test specimen may be accomplished. In a system of this kind, the structure of a desired set of vibrations in the test specimen is shown as a stationary display 13^{a}. Each signal is composed of a series of consecutive points, of which the height above the baseline is a measure of stress. If the scanning rate is low, these points may be brought into contact so as to form a wavy line that corresponds to the waveform of the mechanical vibration in the test specimen.

To accomplish this, the switch 8 is brought into the lower position as illustrated in Figure 1; this will cause the step voltage output of the generator 7 to pass to the Y electrodes of the cathode-ray tube 4. The increases in step voltage are synchronized with the pulses generated by the pulse generators in the pulse-shaping circuit 5 in the circuit 3, so that the points of each signal 12 corresponding to the output of a bridge 1 are shifted vertically above the points of the other signals 12 and, at the same time, they are widened by means of the time deflection voltage and, as a result, each part 13 appears in the form of a horizontally extended signal 13^{a} (Figure 13). In this manner it becomes possible to observe the characteristic of the fluctuations in the amplitude of the physical value being measured in detail.

If photographs are taken, it is preferable to remove the timebase voltage of the X electrodes of the tube and to pass the sensitive film at a suitable speed.

By using barrier circuits, it is possible to select any of the lines of pulses corresponding to a given signal and to pass it to an external measuring instrument such as a counter or recorder.

Each of the bridge circuits 1 is arranged in the configuration illustrated in Figure 4; the arms of the bridge consist of pure resistances with a fixed ratio 14, found at a suitable location of the setup. These arms are connected to the other two arms of the bridge 1 through compensated or shielded wires 15. The other two arms consist of a measuring element 16 and a compensator 17 arranged in such a manner that the measuring element is subjected to the physical value being measured and the compensator corresponding to it is not. However, the latter has such electric characteristics that under the prevailing conditions it is equivalent in this respect to the measuring element 16. Such arrangement is conventional and well known.

The bridge 1 is fed by a square direct current pulse P_1 having a short period; a pulse P_2 comes from the opposite diagonal of the bridge. The latter has an amplitude that depends on the degree of the asymmetry of the bridge circuit 1. This pulse P_2 will have a different configuration because of the combination of resistance, inductivity, and capacity prevailing in each real circuit. Depending on the conditions prevailing in the bridge circuit 1, the first part of the pulse may be rounded; it also may — as illustrated — overshoot and decay at the level p.

The pulse generator circuit 3 consists of the measuring element system illustrated in Figure 1; it has 11 steps (see Figure 5), of which ten are identical and connected to the corresponding bridge circuits 1, and the eleventh is a delay or gap step during which delay or gap period the direct current level of the amplifier is reestablished. The period also permits the resetting of the time base circuit, so that the picture in the cathode-ray tube remains in step with the output of the various bridge circuits 1, and none of the end signals 12 is covered. Each pulse generator circuit consists of a dual triode 18 connected to form a compensated multivibrator circuit, with one anode 19 being connected to the first bridge relay 1 (illustrated schematically in Figure 5) and the next step through a capacitor 20. The circuit of each tube 18 is arranged in such a manner that it generates an excitation pulse lasting for the eleventh of the full operating period of the circuit 3, and each output pulse serves to trigger the next step, so that the pulses follow each other from the first pulse to the eleventh pulse which in turn triggers the first step at the beginning of the next operating period. In this manner each bridge circuit 1 is sequentially triggered by a pulse so that only a single bridge is excited at any given time. During the period in which the eleventh step generates the pulse, no bridge is excited, and no power is fed to the amplifier 2.

A short pulse is generated in the pulse-forming circuit 5 (Figure 1) and then fed to a tap 21 (Figure 5) on the common cathode of the pulse generator 18 of the pulse generating circuits 3. This pulse is generated simultaneously with the beginning of the excitation pulse on each anode 19; it serves to make the waveform more precise and to ensure that the pulse generating circuits 18 remain precisely in step.

Since the amplifier 2 is of the a.c. type, it has a limited time constant; as a result, a tendency to shift the zero point of its output is evident. In order to rectify this, a barrier circuit is connected to one step of the amplifier, preferably to the terminal step. Such a circuit is illustrated in Figure 6. In the arrangement illustrated in this figure, the last step of the amplifier consists of a double triode 22 which is fed by a symmetric input 23. Each grid of the double triode 22 is connected to the anode of the barrier tube 24; the grids of the latter are connected to each other and are fed by pulses (see 25) from the anode 19 of the eleventh step of the pulse generator circuit 3 (Figure 5). The purpose of the barrier tube 24 is to ground the grid of tube 22 once during each cycle of the pulse generators 3 and — on the other hand — to reestablish the zero level of the amplifier output as a result. /5

In order to set the zero level of each bridge circuit 1, the input pulse may be fed through the slide of a voltage divider 26, that connects the adjacent bridge arms (Figure 7). Each bridge 1 must be adjusted by the zero position 26, so that the signals 12 on the cathode-ray tube 4 are correctly displayed. The sensitivity of each bridge is adjustable also; for example, by means of one or more adjustable resistors 27 connected to the output circuit.

In cases where the bridge circuits are also in parallel connection, it must also be realized that they may also be connected in series if desired, or be coupled through transformers.

Figure 8 illustrates a bridge circuit 1^a for measuring frequencies. In this circuit, the measuring element consists of a thermal resistor 16^a or another element, of which the resistance is a function of the current flowing in it, and a resonance circuit 28, 29 is connected to one diagonal of the bridge. The inductance 28 has a tap 30 in the middle; this is connected to the other end of the thermal resistor. Such a bridge is compensated only if the voltage that develops on the resonance circuit 28, 29 is zero. The value to be measured is applied to the coupling winding 28^a, and the resonance circuit 28, 29 reacts to the presence of a component of the value concerned by a frequency that equals the resonance frequency.

The resulting voltage at the thermal resistor 16[a] changes this resistance and takes the bridge 1[a] out of equilibrium; as a result, the extent of the imbalance is a measure of the amplitude of the component at the appropriate frequency. In the picture that results, as illustrated in Figure 2, the amplitude of the vertical lines 13 corresponds to the magnitude of the frequency component to which the individual circuits 1[a] are compensated. From the picture illustrated in Figure 3, amplitude modulations at any of the frequency components may be determined since they appear as vibrations in the corresponding line 13[a].

The resistance of the thermal resistor 16[a] or similar device will not change significantly during the period of the brief test pulse applied to the bridge 1[a] since it is relatively laggard. The presence or absence of the pulse itself will, therefore, not affect the symmetry of the bridge. A circuit of this type may be used to measure and analyze frequencies, or upper harmonics of a number of bridges 1[a] of the above-described kind are fed by the power source being examined in parallel circuit.

The above-described measuring circuits may be used with measuring elements that convert other physical effects into changes in resistance or reactance. For example, temperature is measured by insertion of a resistance thermometer into one or both of the bridge arms 16 and 17 shown in Figure 4. Moisture may be measured by using a measuring element consisting of a conductive strip made of absorbent material. Illumination may be measured by using a suitable light-conducting cell as the measuring element 16; magnetic field strength may be measured through the change in resistance of a bismuth wire element. A multichannel measuring system may be used for the simultaneous measurement of several physical values from aremote location.

Figures 9 and 10 illustrate another method for using the bridge. In the methods described so far, direct current pulses were employed. The setup illustrated in Figure 9 uses alternating current pulses.

The various bridge circuits are fed by a common frequency-modulated oscillator 30 through corresponding bandpass filters 31; each of these filters being adapted to accepting a characteristic frequency range. The frequency ranges of the filters are chosen to accommodate a certain band, for example between 500 and 1000 kHz. Each filter 31 is designed to accommodate a specific, characteristic frequency range, and the oscillator modulation is brought continuously or stepwise from 500 to 1000 kHz during a period of, say, 100 microseconds, and then brought back in, say, 10 microseconds to 500 kHz. Thus, the filters 31 operate like selector switches so as to excite the corresponding bridges 1 in that part of the period during which the modulation passes through the frequency range assigned to them.

The waveform of a typical modulation is illustrated in Figure 10A. The frequency increases from O to P continuously, and then abruptly drops to the starting value O. This cycle is repeated several times, randomly. Each cycle of such frequency fluctuations is subdivided into ranges OA, AB, ... GH, HP, whereby each of these ranges has a width corresponding to the bandwidth of an assigned filter 31. Each frequency range OA, AB, etc., therefore, appears at the corresponding bridge circuit 1 as a pulse of relatively short duration.

Figure 10B illustrates the manner in which the waveform shown in Figure 10A between the consecutive frequency ranges OA, AB, ... HP in Figure 10A may be successfully amplitude-modulated in order to obtain short periods during which the amplitude drops to zero or close to zero. This would separate the various frequency ranges more sharply from each other and create steeper wavefronts. The rising and falling pulse edges are thus sharply pronounced by means of the amplitude modulation /6 so as to shorten the period of ascension and decline of the current through the filter 31. Piezoelectric crystal resonators may be used instead of the bandpass filters 31 in cases where they are preferable for some reason. The frequency modulation is kept in step with the time base of the cathode-ray tube 4 through a connection between the time base circuit 10. The output wires of all measuring element circuits 1 are connected in parallel and fed through a common amplifier 2 to a cathode-ray tube 4 as illustrated in Figure 1.

Figures 11 and 12 show other setups of the measuring circuits 1. Figure 11 shows a setup in which the bridge 1 is replaced by a pair of symmetric transformers 32, equipped with mechanical devices (indicated at 33) to alter their conversion ratios. In the setup illustrated in Figure 12, two identical capacitors 34 have movable third electrodes 35. Each of these setups are suitable for measuring linear and angular shifts, whereby the parts 33 and 35 are coupled with parts of which the relative displacement is measured.

The resistance bridge circuit shown in Figure 4 may be replaced by a conventional reactance bridge of some kind. For example, the measuring element 16 may be a capacitor designed in such a manner that the capacity value is changed by mechanical movement or shift of the measuring element in a conventional manner. The configuration of the output pulse will be similar to that shown under P_1 in Figure 4, provided that the time constant of the bridge 1 is not smaller than the period of the pulse; preferentially it is at least ten times as long.

The bridge elements 16 and 17 may be inductances; one or both designed in such a manner that the inductance is changed by mechanical movement of a ferromagnetic core. If, under such circumstances, a square pulse is applied to the bridge, the output pulse rises at the opposite diagonal to a maximum value and decreases exponentially. The square configuration of the pulse, for which the display is designed, may then be reestablished by inclusion of a differentiating circuit between the bridge 1 and the amplifier 2. The differentiating circuit may consist of a small capacitor in series with one or both output wires, whereby the time constants of the capacitor and the circuit loading are smaller than the pulse period.

Undesirable components result from blind or effective resistance when capacitive or inductive bridge branches are used. They are eliminated by measuring the height p of the pulse P_2 (Figure 4) in the above-described manner.

The method covered by the invention has certain advantages in cases where the effects to be measured occur on parts that are relatively inaccessible or are in motion, since the connection between the measuring element may be established by means of capacitive or inductive coupling. In cases where pulses are obtained by modulation of an alternating current, there is no need for separate inductive or capacitive couplings for each of the channels to the measuring elements on the rotating or otherwise moving part. The frequency-selective circuits may be fitted to the moving part, so that only a single outgoing and a single returning path is needed for the signals of, say, ten elements for the measurement of the stresses. These paths may be established by means of radio transmission.

As shown in Figure 13, for example if it is intended to measure the stresses at various portions of a propeller 36 in a flying aircraft 37, it is possible to couple the measuring element bridges 1 and bandpass filters 31 in a circuit of the kind illustrated in Figure 10 in such a manner to the readout instrument 4 that there is no need for having brush contacts on the propeller shaft. The parts of the bridges 1 and the filter 31 may be fitted directly to the propeller blade in the manner illustrated in Figure 13. The manner in which a remote measuring system may be used between the aircraft 37 and a ground station 38 is also indicated. In the illustration, a frequency-modulated oscillator of the kind shown in Figure 10 is coupled with a series of bandpass filters 31 and measuring bridges 1 through the wires 38 which lead through the propeller shaft 39 and are connected at their inner ends by means of insulated slide rings 40 forming one electrode of a capacitor of which the other electrode 41 is connected to the output of the oscillator 30. A similar capacitor coupling 42, 43 connects the measuring element output lines 44 with an amplifier 2^a, of which the output is fed through a transmitter 45 to an antenna 46. The transmitter modulates a carrier wave with the output pulses.

An antenna 47 in the ground station receives the waves radiated from the aircraft (the ground station is identified by the symbol 38); it then transmits the signals to a receiver 49. The receiver output is divided, one part goes to an amplifier 2^b which passes the amplified measuring element output pulses to the Y electrodes of the tube 4. The other part of the output is passed to a stroboscope 50 and time base 10, and thereafter to the X electrodes of the tube 4. By using this setup, the carrying of heavy and sensitive control and measuring devices in the aircraft is avoided. Temperatures or other physical parameters may be measured in other rotating, reciprocating, or vibrating parts from a remotely located test area. If so desired, the pulses from the individual measuring elements may be separated from those from other measuring elements, and measured with different instruments. For example, it is possible to measure various locations of a test part subjected to particularly high stresses while the part is in actual use.

A major advantage of the invention is the possibility of measuring precisely a shock pulse that lasts for a mere few microseconds. /7

It was found that conventional wire resistor elements are suitable for the measurement of stresses with pulses lasting for 10 microseconds at a frequency of 10 kHz. The height p of the pulse P_2 in Figure 4 is then of adequate duration for measuring in the above-described manner.

The period of the initial perturbance of the output pulse P_2 may be shortened by reducing the scatter reactances in the circuit, as well as by reducing the time constants through the use of a low impedance for the measuring element. Then it becomes possible to use shorter pulses and, thus, higher frequencies of mechanical stress may be depicted.

An improved wire measuring element is shown in Figure 14. It is connected to a symmetric two-strand wire 36 to the circuit; it consists of a conventional fine wire resistor wire in zigzag arrangement 37, adhesive-mounted to a flexible substrate strip 38. The resistance of the element is best made to equal the impedance of the symmetric two-strand wire 36.

Figure 15 shows a similar setup, in which a shielded concentric wire 39 is used. The center conductor 40 is connected at one end of the wire element 37 and the outer mantle 41 is connected at the other end. The outer mantle 41, which may be a copper-wire braid, is extended to form an electrostatic shield 42 around the wire measuring element; the entire unit is mounted on the flexible metallic or non-metallic substrate or carrier 38.

Figure 16 shows a shielded two-strand cable 36^a and two measuring elements 37 and 37^a that form the two arms 16 and 17 of the bridge circuit 1 in Figure 4. The element 37 is adhesive-mounted on the flexible substrate or carrier 38, and the element 37^a is adhesive-mounted to a substrate 38^a. The latter substrate is attached to the main substrate 38^a only at one end, so that the element 37^a is not subjected to any stress. A flexible metallic mantle 42 sheaths the two measuring elements; it is mounted on the substrate 37.

In the above-described designs, the zigzag wire resistance element may be replaced by a conductive cover or a layer in order to improve the electric performance of the measuring element as a high-frequency terminal for the cable, reducing its inductance.

CLAIMS OF PATENT

1. Method for measuring a physical value with the aid of an electric measuring device which is incorporated in one branch of a bridge circuit, characterized by the fact that the bridge is fed by a series of pulses of electric energy with a relatively high repetition frequency, wherein a selected characteristic of the resulting modulation of the pulses is established (for example with the aid of bandpass filters).

2. Method according to Claim 1, characterized by the fact that the selected characteristic of the pulse modulation is visibly displayed.

3. Method according to Claim 1 or 2, characterized by the fact that the physical effects are measured simultaneously on a number of locations by means of feeding pulses from the same source sequentially to measuring devices at said location.

4. Method according to Claim 3, characterized by the fact that several selected pulse modulation characteristic lines are indicated on a common measuring device or are measured on same device.

5. Method according to Claim 1, 2, 3, or 4, characterized by the fact that the pulses are generated by amplitude modulation of a direct current.

6. Method according to Claim 1, 2, 3, or 4, characterized by the fact that the pulses are generated by amplitude modulation of an alternating current.

7. Method according to Claim 5 or 6, characterized by the fact that the degree of modulation is 100%.

8. Method according to one of Claims 1 to 4, characterized by the fact that the pulses are generated by frequency modulation of an alternating current of high frequency for short discrete time periods.

9. Method according to Claim 8, characterized by the fact that several measuring devices are fed by pulses from a common source of alternating current, and each measuring device is fed by a pulse having a different modulation frequency that is characteristic for the measuring device concerned.

10. Method according to Claim 9, characterized by the fact that the frequency of the modulation is progressively changed from a starting level to a final level and then dropped rapidly to the starting level during each cycle, and that this sequence is repeated for each subsequent cycle and that each measuring device is fed through an appropriate band-pass filter tuned in such a manner that it accommodates a frequency range that is characteristic for the measuring device concerned.

11.Method according to Claim 9 or 10, characterized by the fact that the duration of each pulse continues to be defined by the amplitude modulation of the alternating current.

12. Method according to one of Claims 1 to 4, characterized by the fact that the pulses are generated by phase modulation of an alternating current for brief period of time.

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13. Method according to one of the foregoing claims, characterized by the fact that the output, or each output, of the measuring device is demodulated and measured by separate devices.

14. Method according to one of Claims 1 to 13, characterized by the fact that the pulses derived from a measuring device are reconstructed in their configuration before they are fed to the measuring or display periods.

15. Method according to one of the foregoing claims for the measurement of physical values in relatively inaccessible locations, characterized by the fact that the measuring device is coupled to the measuring or display instrument through broadcast connection.

16. Electric measuring device, characterized by the fact that there is a measuring instrument connected to one branch of a bridge circuit, a pulse generator to generate pulses of relatively high pulse repetition frequency to feed a measuring instrument and means to display a characteristic modulation of the pulses by the measuring device if it is exposed to the physical effects to be measured.

17. Apparatus according to Claim 16, characterized by the fact that a measuring device is connected in one branch of a Wheatstone bridge circuit to which the pulses are fed diagonally.

18. Apparatus according to Claim 16 or 17, characterized by the fact that the pulse indicating or display unit encompasses a pulse amplifier and a cathode-ray tube.

19. Apparatus according to Claim 16, 17, or 18, characterized by the fact that several measuring devices and means are provided to feed pulses in a predetermined sequence to said apparatus.

20. Apparatus according to Claim 19, characterized by the fact that the outputs of the various measuring devices are fed to a common indicating or display unit.

21. Apparatus according to one of Claims 16 to 19, characterized by the fact that the pulse generator operated in such a manner that it generates direct current pulses.

22. Apparatus according to one of Claims 16 to 19, characterized by the fact that the pulse generator operates in such a manner that it generates alternating current pulses.

23. Apparatus according to Claim 22, characterized by the fact that the pulse generator encompasses means for the amplitude modulation of high-frequency alternating currents for the generation of pulses.

24. Apparatus according to Claim 23, characterized by the fact that the degree of modulation is 100%.

25. Apparatus according to one of Claims 16 to 19, characterized by the fact that the pulse generator has means for phase modulation of an alternating current for short periods of time, whereby each corresponds to the desired pulse duration.

26. Apparatus according to one of Claims 16 to 19, characterized by the fact that the pulse generator encompasses a frequency-modulated oscillator, and has means for feeding a modulated output therefrom to a measuring instrument to generate short periods of equal intervals for the purpose of generating pulses.

27. Apparatus according to Claim 26, characterized by the fact that there is a number of measuring instruments, a frequency-modulated oscillator, means for cyclically altering the modulation frequency progressively from a predetermined initial level to a predetermined final level, followed by an abrupt reestablishment of the initial value during each cycle, as well as means connected between the oscillator and the corresponding measuring instrument operating in such a manner that they pass a specific frequency range to the oscillator input, whereby said frequency range is characteristic for the measuring instrument concerned.

28. Apparatus according to Claim 27, characterized by the fact that each measuring instrument is connected to the oscillator through a bandpass filter.

29. Apparatus according to Claim 27, characterized by the fact that each measuring instrument is connected to the oscillator through a piezoelectric crystal resonator.

30. Apparatus according to Claim 27, 28, or 29, characterized by the fact that an amplitude-modulating circuit is connected to the oscillator, whereby said circuit is synchronized in such a manner that the amplitude of the oscillator output is abruptly reduced for a brief period between consecutive frequency bands.

31. Apparatus according to one of Claims 16 to 30, characterized by the fact that the pulse is fed to one measuring instrument by means of an inductive or capacitive coupling.

32. Apparatus according to one of Claims 16 to 19, characterized by the fact that there are means for demodulating the measuring instrument output and measuring the demodulated output at a separate measuring device.

33. Apparatus according to one of Claims 16 to 19, characterized by the fact that there are means for reestablishing the configuration of the pulses derived from the measuring instrument before they are fed to display instruments.

34. Apparatus according to one of Claims 16 to 31, characterized by the fact that each measuring instrument is coupled to a separate measuring or display device by means of radio transmission.

35. Apparatus according to one of Claims 16 to 34, characterized by the fact that the measuring instruments encompass a resistance element mounted on an insulating substrate and that the element is surrounded by a conductive layer. /9

36. Apparatus according to Claim 35, characterized by the fact that a second, identical resistance element is mounted to a holder adjacently to the first element in such a manner that it is protected from the physical effects being measured.

37. Apparatus according to Claim 35 or 36, characterized by the fact that the resistance element has a conductive film or coating, as well as a layer that surrounds the film, and that the parts are designed in such a manner that the measuring instrument forms a tuned terminal for a high frequency wire to establish connection between the measuring instrument and the test circuit.

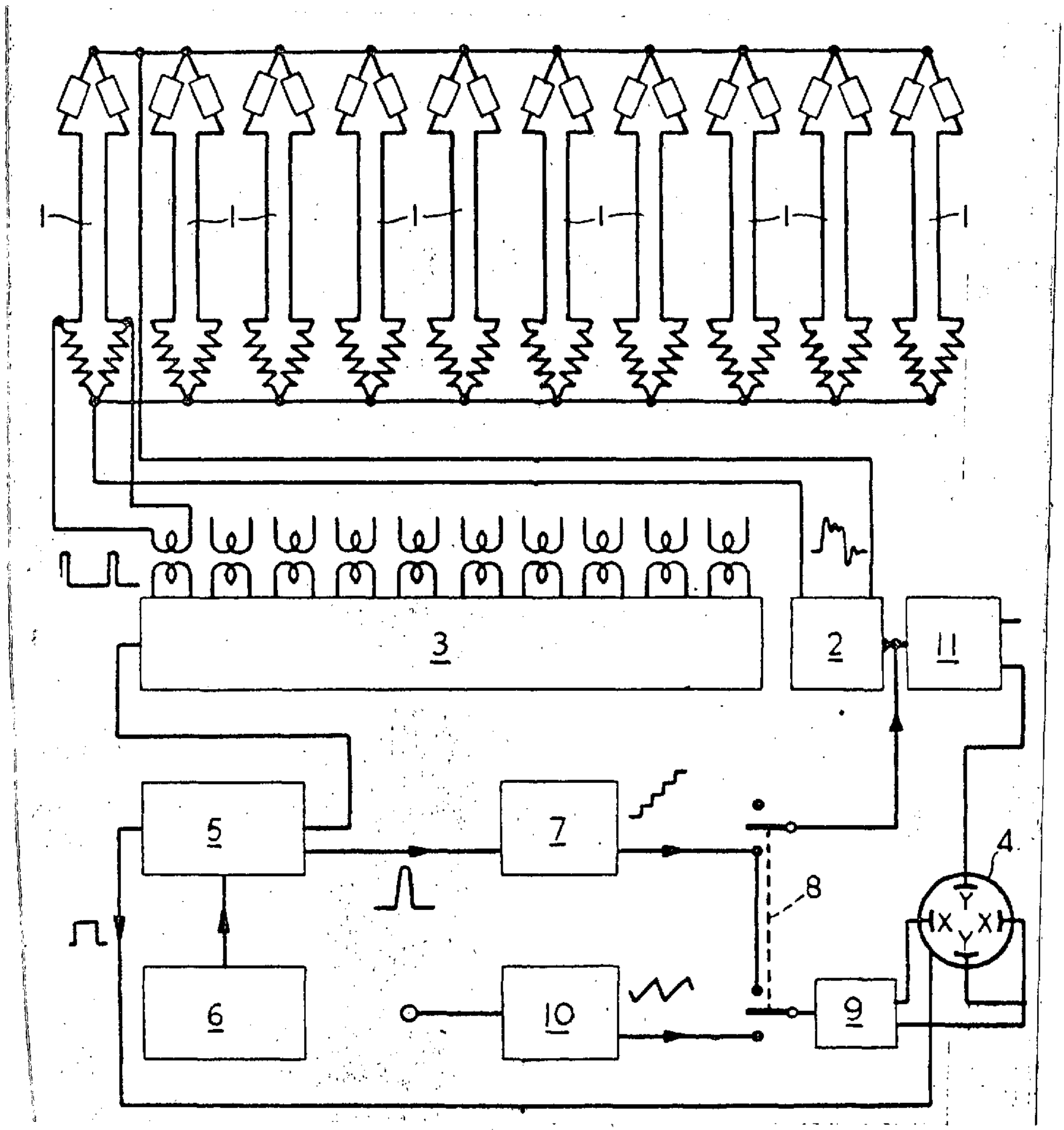


FIGURE 1

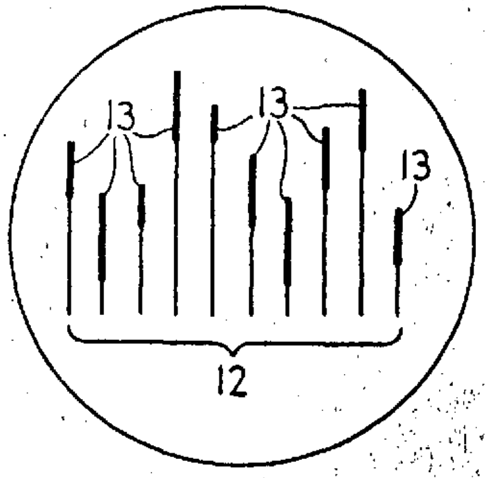


FIGURE 2

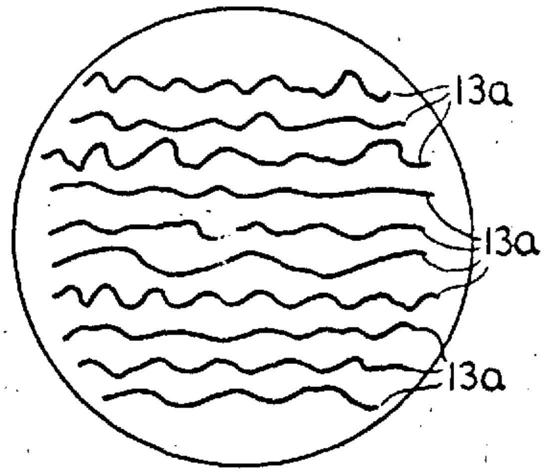


FIGURE 3

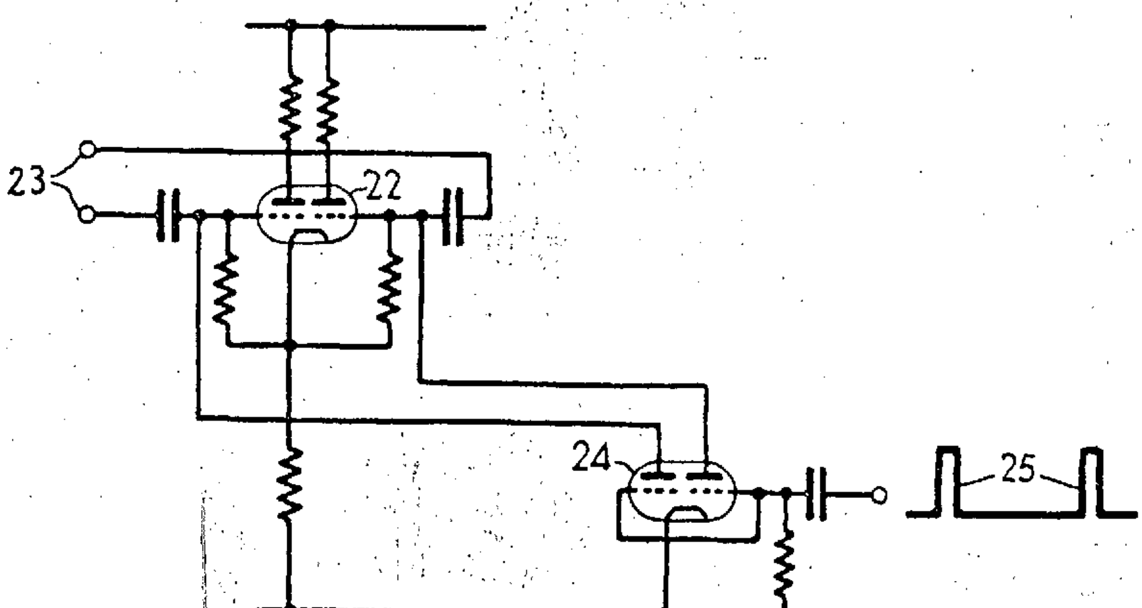
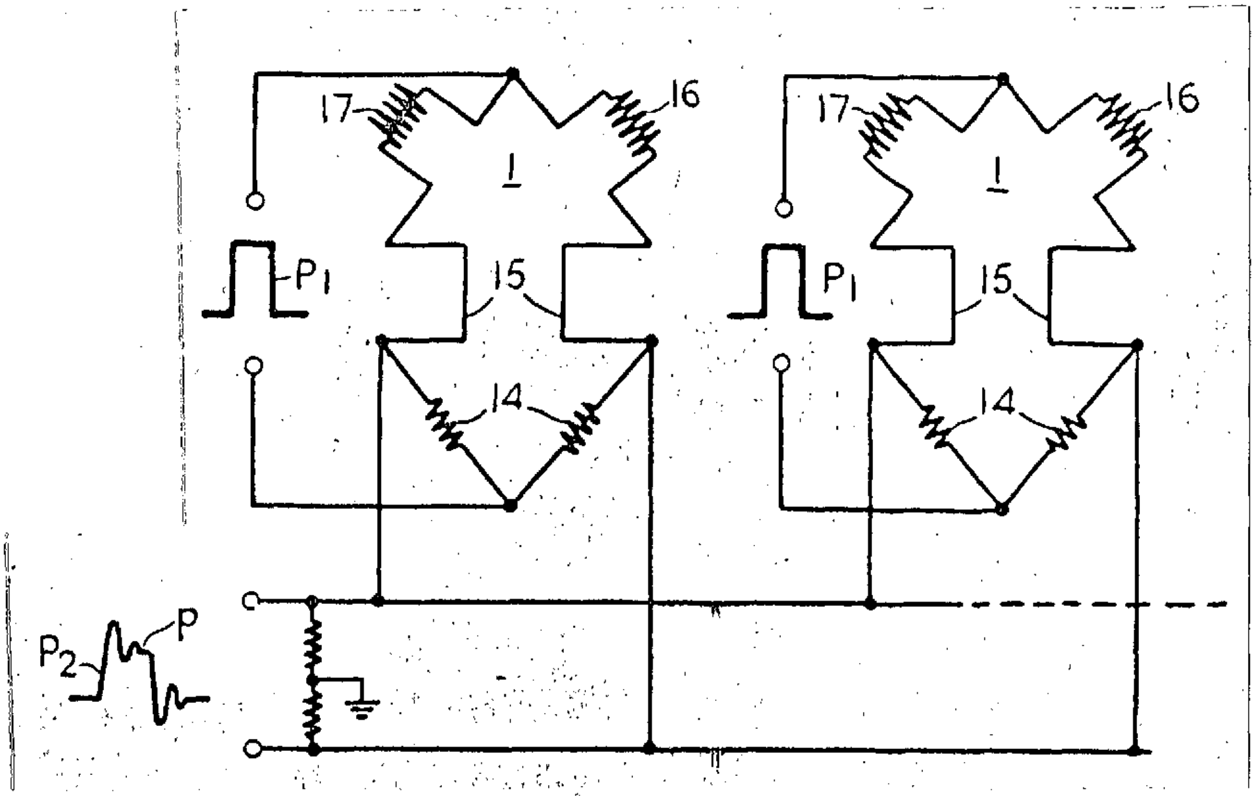


FIGURE 6



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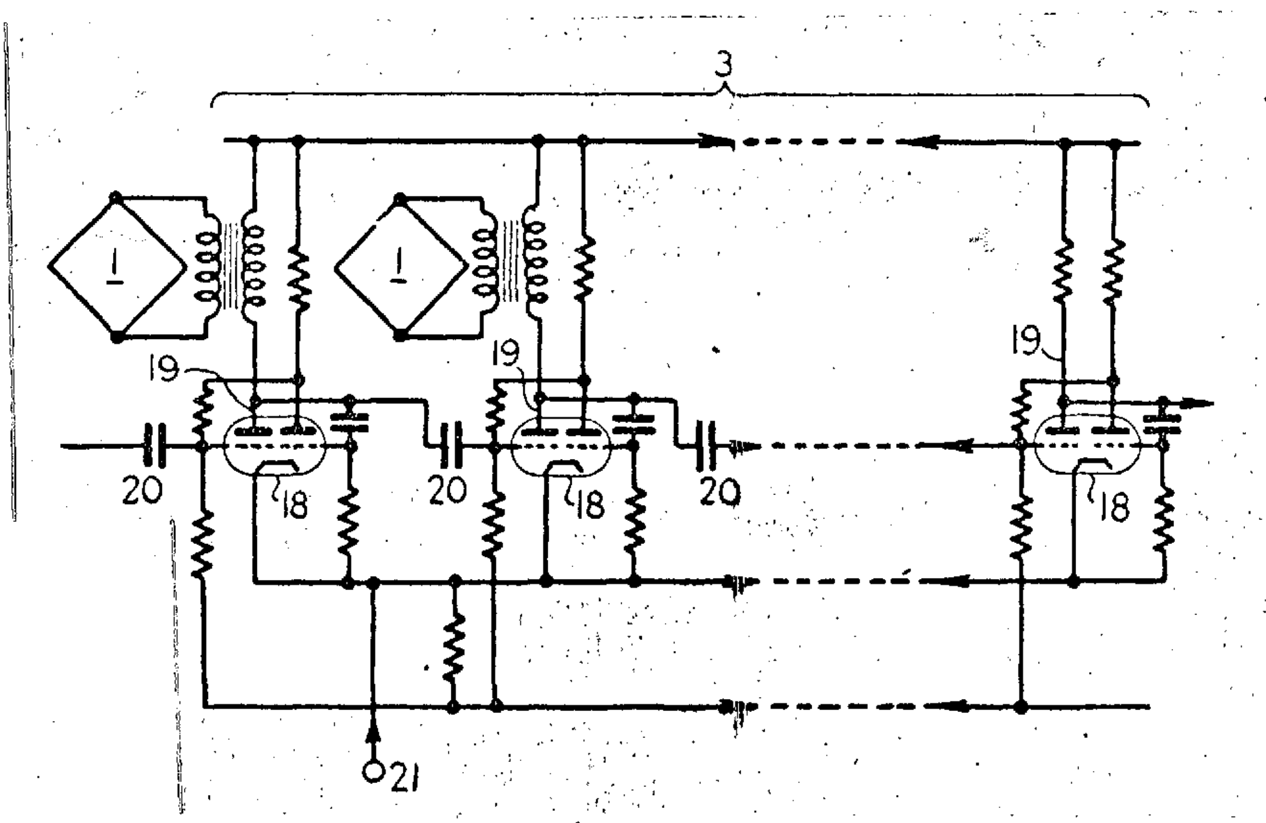


FIGURE 5

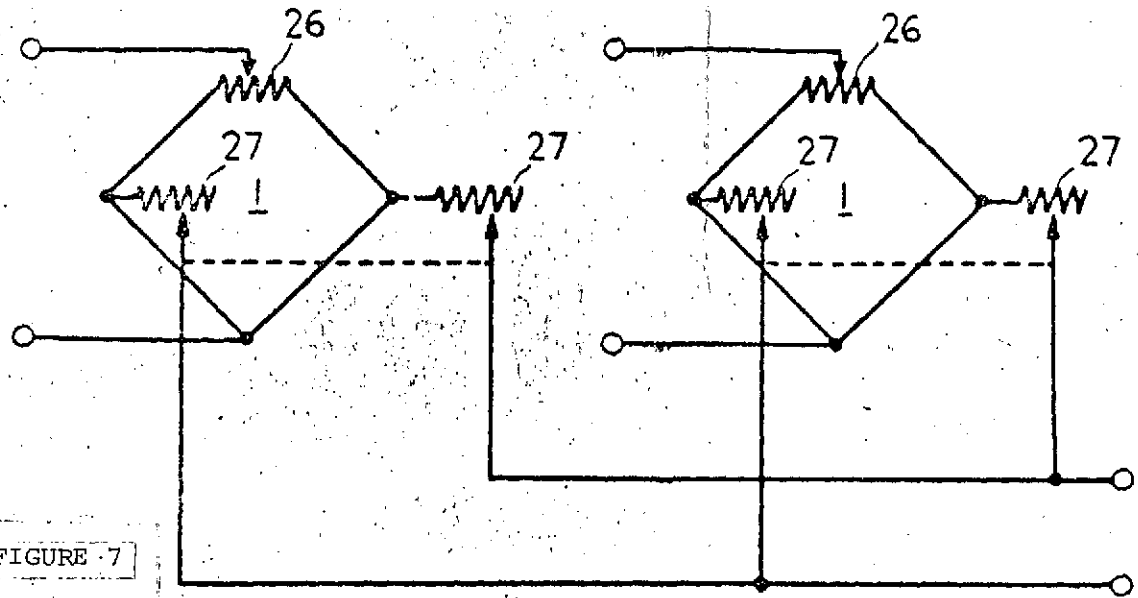


FIGURE 7

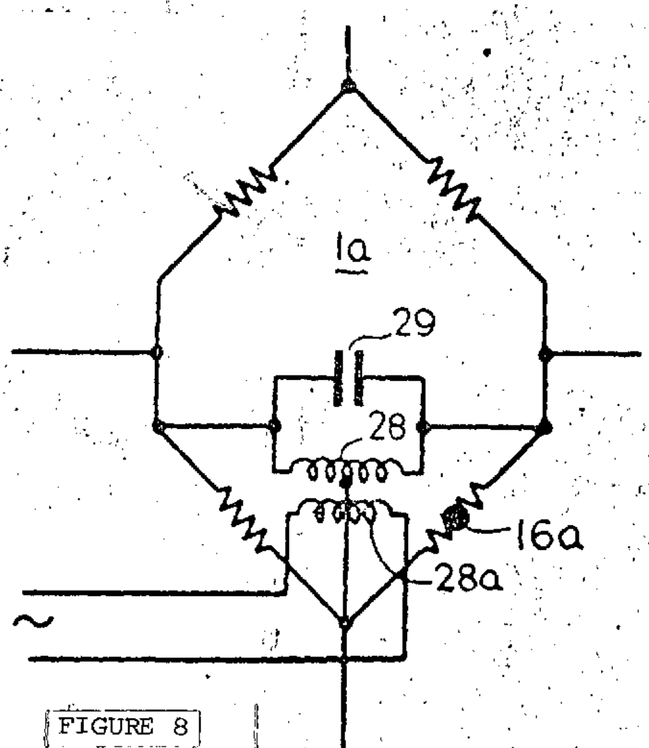


FIGURE 8

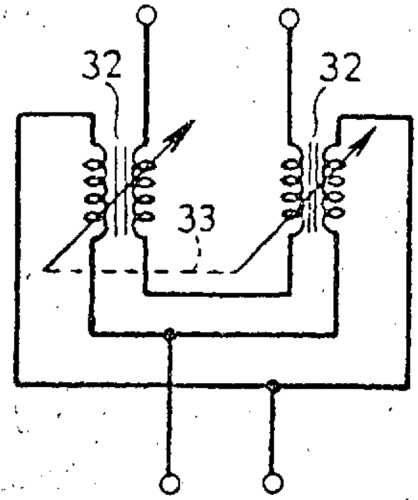


FIGURE 11

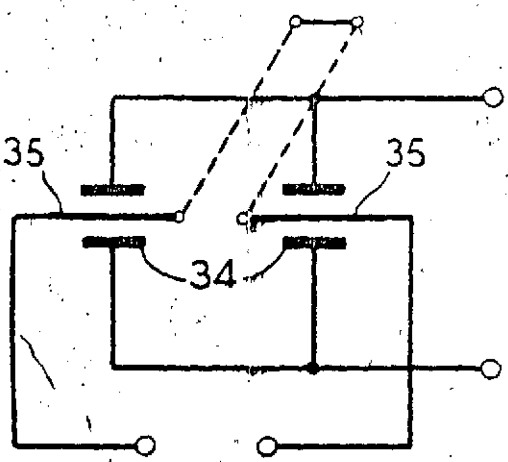


FIGURE 12

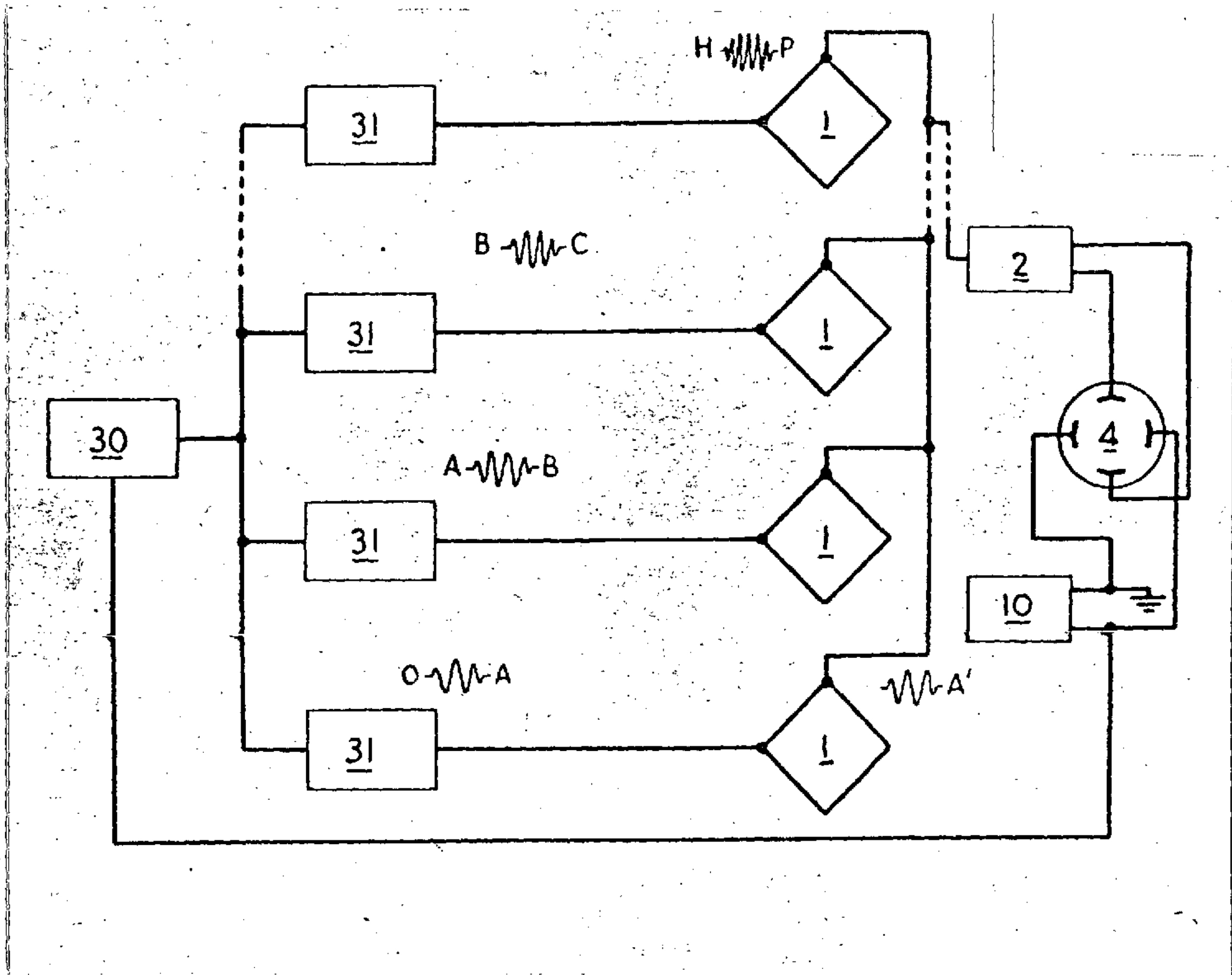


FIGURE 9

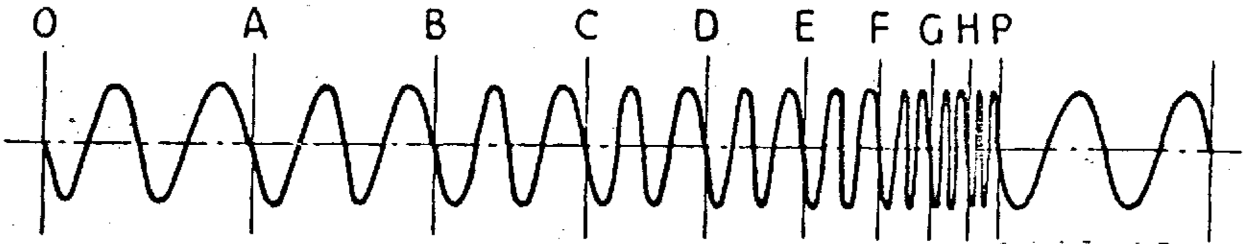


FIGURE 10a

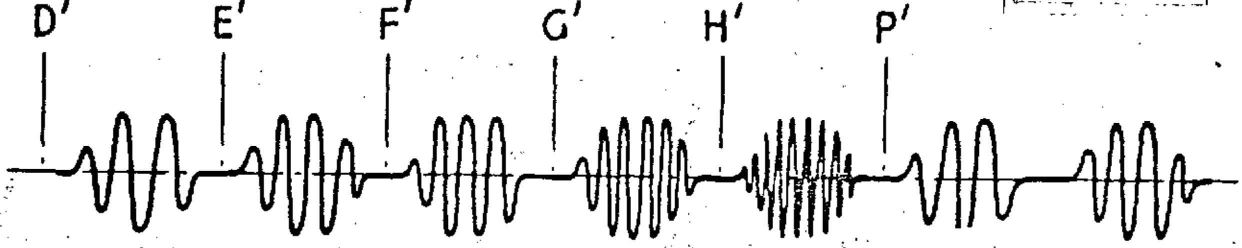


FIGURE 10b

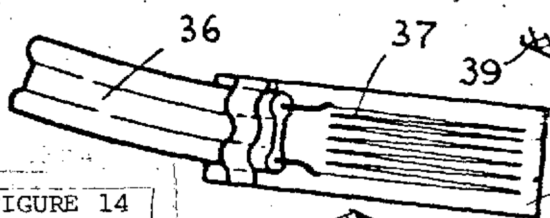


FIGURE 14

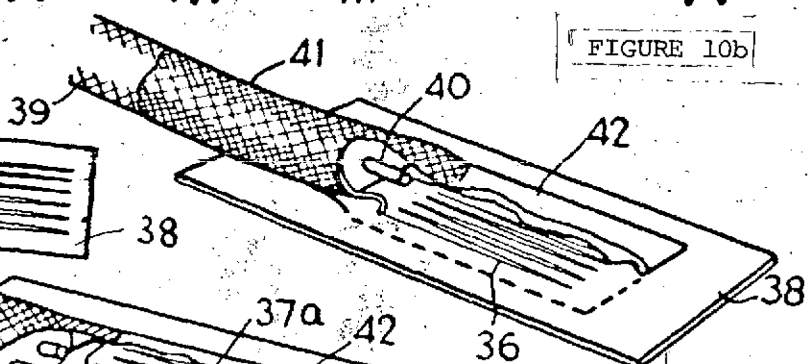


FIGURE 15

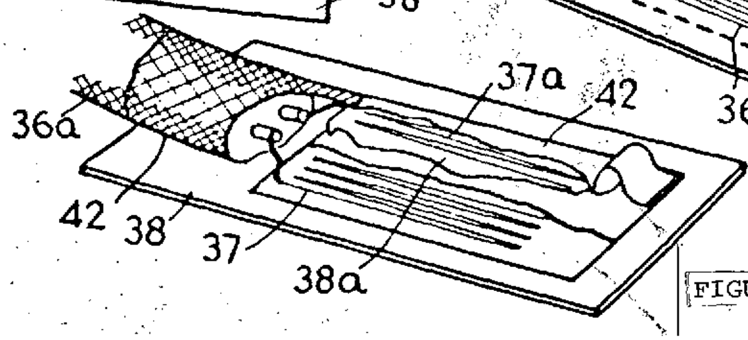


FIGURE 16

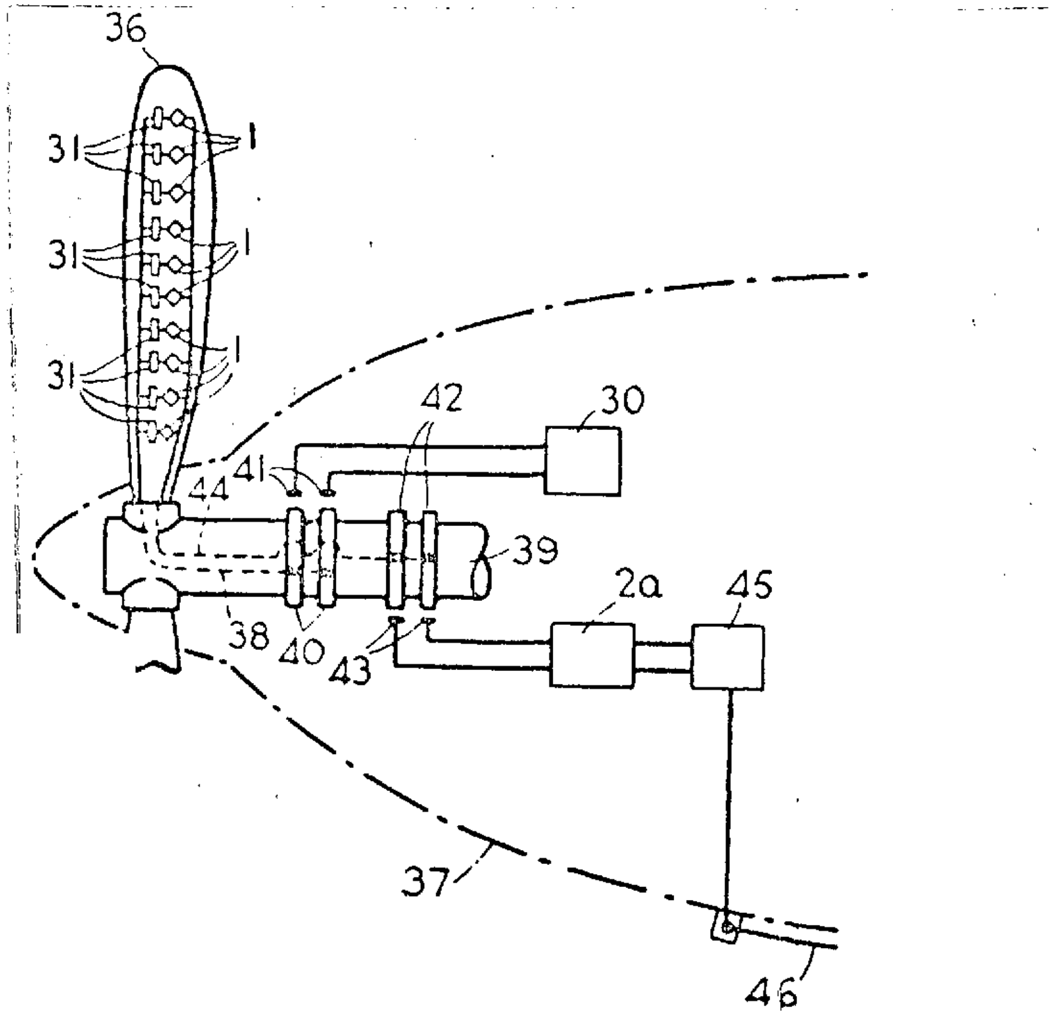
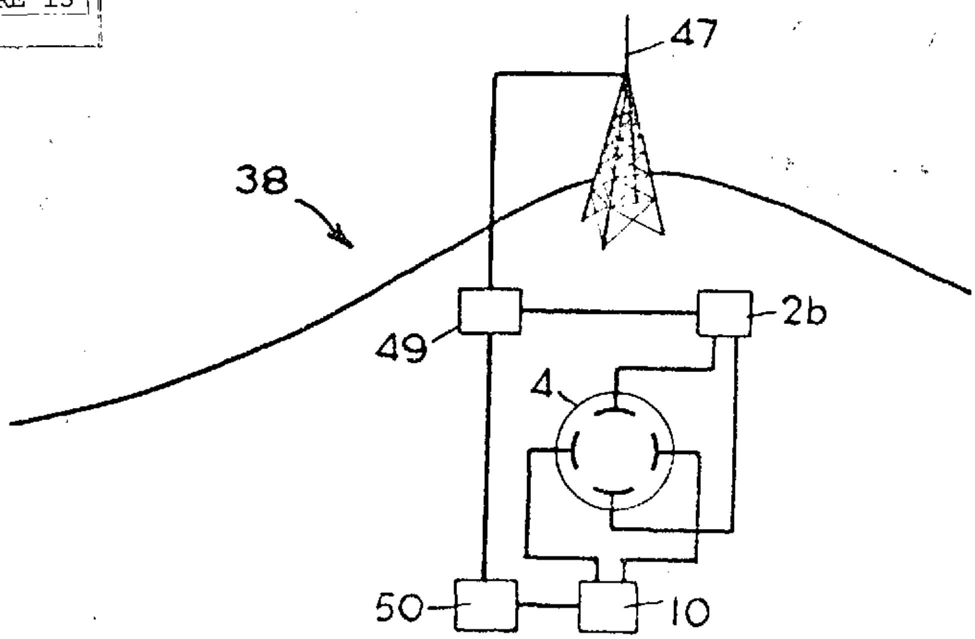


FIGURE 13



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